

March 2016

# Incorporation of 3D Printing in STEM Curricula

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## Incorporation of 3D Printing in STEM Curricula

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*Date:* April 30, 2015  
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*Project:* 3D Printing for  
Education

### Abstract

3D printing itself is not a brand new technology. The first 3D printer was invented in 1983 by Charles Hull[19]. Until recent years the technology was mainly only available for industrial use. The first desktop 3D printer was created in 2001 by Solidimension[19]. Since then the technology has become less and less expensive making it more available to the general public. Different methods for the use of 3D printers and other manufacturing technologies in educational settings were developed to further familiarize the engineers of tomorrow about useful technology.

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## 1 Introduction

### 1.1 Objective

The goal of this project is to integrate 3D printing and 3D printed parts into lesson plans that can be used to teach key engineering concepts in engineering classes in grades K-12.

### 1.2 Rationale

Recently 3D printing companies have been trying to get children more excited about 3D printing and explore the possibilities of having a 3D printer at their disposal at school. The problem encountered with most 3D printers that are donated to schools is that it sparks the interest of the children, but not for a long time. Most of the time when 3D printers are introduced to children or anyone that does not have a defined purpose for using it, the printer is used to make a few trinkets or toys and then is no longer used. The availability of other technology such as the Internet and smart devices has drastically changed the way children learn and absorb information. This makes it much more difficult to make them interested in sitting through lectures and being told information. Based on a study done by Jim Parsons, a professor of 35 years at the University of Alberta, children today are more likely to want to problem solve themselves and require a more interactive curriculum to help them retain what they have learned[14]. Therefore a new form of teaching involving technology can be adapted to current methods.

### **1.3 State of the Art**

This project presented new challenges in terms of helping students learn through the use of existing 3D printing technology. There are a few existing programs that are attempting to implement 3D printing curricula described below. However, these organizations are not taking the same approach. The goal of this IQP is to find ways to allow 3D printing to supplement existing curricula and help teachers teach engineering courses. The incorporation of 3D printing into the classroom makes lessons more interactive while not taking time away from what the students are learning, and gaining their interest in STEM fields. The other programs are supplemental material that take more effort to incorporate into current lesson plans. Teaching standards for schools can be limiting in this respect, making the approach of taking existing curriculum and creating lesson plans around them easier to implement and more likely to be used by teachers in the future.

#### **1.3.1 Existing 3D Printing Educational Programs**

##### **1.3.1.1 PrintrBot Learn**

PrintrBot Learn is an educational initiative currently being developed[11]. It focuses on teaching students how to use and maintain 3D printers. Activities were developed to teach students a physics lesson with 3D printed rockets[1].

##### **1.3.1.2 Stratasys 3D Printing Curriculum**

The Stratasys 3D printing curriculum focuses on teaching students how to use Stratasys 3D printers. The course objectives of this program are listed below [13].

- Produce a fully functional moving part in a single print
- Explain current and emerging 3D printing applications in the manufacturing field
- Understand the advantages and limitations of each 3D printing technology
- Measure the effect of the program
- Evaluate scenarios and recommend the appropriate use of 3D printing technology
- Identify opportunities to apply 3D printing technology for time and cost savings

##### **1.3.1.3 MakerBot in the Classroom**

The MakerBot in the Classroom program includes several project ideas involving 3D printing

that can be incorporated into a science curriculum. The handbook for this program divides the curriculum into sections. These sections are: a primer on 3D printing technology; explanations of how to download, scan, and design models to print, and sample 3D printing projects[7].

### **1.3.2 Education in Massachusetts**

A major challenge encountered when first developing the curriculum was finding out where this sort of project would be most helpful. Physics courses, math courses, and technology courses were considered. In order to see a direct benefit from the work put into this project, local teachers were contacted for partnership on the project. The objective of the project was to incorporate 3D printing to help teach students key engineering concepts and supplement their learning. The incorporation of a partnership with a teacher allowed direct feedback and allowed the focusing of development of materials on subjects that the students needed to learn for their classes. The final decision involved incorporating 3D printing into the existing Project Lead The Way curriculum given to high school students.

#### **1.3.2.1 Core Curriculum**

The core STEM curriculum standards for K-12 students in Massachusetts are outlined below[8]. This project calls for a class that is more physics and engineering based. The core curriculum standards for physics appeared less flexible than those for the engineering classes. The engineering class core curriculum standards are outlined below in terms of seven subtopics.

- Engineering Design
- Construction Technologies
- Energy and Power Technologies - Fluid Systems
- Energy and Power Technologies - Thermal Systems
- Energy and Power Technologies - Electrical Systems
- Communication Technologies
- Manufacturing Technologies

The high school students have the opportunity to explore any of the topics listed above. However, middle school students are limited to a less extensive version of Engineering Design. A more in depth description of these standards can be viewed using the link to the Massachusetts Department of Education Science and Technology/Engineering Framework in the reference section

of this paper. These classes are generally taught through the Project Lead The Way Program described below.

### **1.3.2.2 Project Lead the Way (PLTW)**

Project Lead The Way (PLTW) is a non-profit organization that partners higher education institutions like WPI with secondary education schools and the private sector to deliver and implement an intensive pre-engineering curriculum to high school and middle school students. The lesson plans developed for STEM classes were incorporated into the curriculum for various PLTW classes including Principles of Engineering (POE), Introduction to Engineering Design (IED), and Civil Engineering and Architecture[15]. This will be done through contacting local PLTW teachers to assist in the incorporation of 3D printing in their lesson plans.

### **1.3.3 Different Teaching Approaches: Active Learning vs. Traditional Learning**

#### **1.3.3.1 Traditional Learning**

Traditional instruction is a more teacher-centered approach. Classes involve lectures where the teacher provides students with information, the students take notes, and students study for an exam through memorization and practice. Traditional learning typically involves the passive student, that just absorbs the information that is fed to them[10].

#### **1.3.3.2 Active Learning**

Active learning is a process whereby students engage in activities, such as reading, writing, discussion, or problem solving that promote analysis, synthesis, and evaluation of class content[9]. Some methods used to promote active learning include simulations, collaborative learning, cooperative learning, and problem-based learning. Through the analysis of 225 different studies it was found that active learning methods increased student performance.[12] Research also indicates that average failure rates in students learning material through traditional methods was 33.8% whereas students learning through active learning methods had a failure rate of 21.8%[12]. Along with discussions and problem solving, technology has also been used as a tool in active learning. Studies incorporating technology and active learning in the classroom have been previously explored and proved to be more effective than traditional means of teaching. A notable experiment Technology-Enhanced Active Learning (TEAL) conducted at MIT used an active learning format with freshman physics classes including a lecture, recitation, and hands on experiment[20].



The instructors would give a 20 minute lecture with discussion questions, visualization via simulation, and hand written exercises. The results of this study showed that interactive engagement in learning doubled the average normalized learning gains for low, intermediate, and high scoring students when compared to traditional instruction[20].

### **1.3.3.3 Active Learning Methods/ Definitions**

As noted earlier, the main methods of active learning are simulations, collaborative learning, cooperative learning, and problem-based learning. The use of simulations is an easy way to present information and have students interact and understand material through visualization. Collaborative/ Cooperative learning involves “learning activities expressly designed for and carried out through pairs or small interactive groups[2].” Some collaborative learning activities are coached problem solving, guided discovery problems, peer assessment, and problem and project-based learning. Problem-based learning challenges students with a complex, real-world problem where students can collaborate in groups to understand the problem and come up with potential solutions[17]. These methods have proven to surpass traditional instruction in terms of retention of material and motivating students to study and develop their thinking skills [3].

## **1.4 Approach**

The lesson plans developed will not only utilize 3D printing as a tool, but also active learning principles. Background research reveals that the active learning approach may offer many advantages over traditional instruction. In particular, active learning leads to better retention of the material learned which is important when developing foundations for STEM fields. This project will include the development of an active learning-based curriculum for STEM related fields utilizing manufacturing technology as a learning tool. As a part of the active learning experience, a team of WPI students will be deployed to be involved in the STEM exercises at local schools, instructing and interacting with the students. This differs from many technology workshops in that instead of having the K-12 students come to a manufacturing lab and learn there, the workshop would bring the technology to them. This would enable them to be introduced to manufacturing tools, including tools that can become a part of their classroom setting such as 3D printers.

Our approach also takes the best aspects of traditional learning while keeping the students active. A lecture style presentation will be used to display new material and keep the attention of the entire class at one time. Examples were placed in the presentations to build the lecture material with direct applications. Generally after a presentation was completed there would be a hands on section. These hands on sections used teams, so problem solving skills could be brought out via group collaboration and cooperation.

## 2 Project Goals

- Create scalable curriculum using practical 3D printed examples and interactive activities;
- Create lesson plans that can easily fit into current curricula for K-12 students;
- Educate students about manufacturing technology;
- Promote Engineering and Manufacturing;
- Show students and teachers that tools such as 3D printing can be aids in learning engineering concepts;
- Provide proper documentation for continuation of this IQP for next year;
- Measure the effect of the program through means of survey of students;

## 3 Methods

### 3.1 Contact with Teachers

This project required working with a local teacher to help develop and test the curriculum. This left a lot of different options for finding a teacher to work with. The first approach to finding a teacher was organized by getting in touch with the STEM Education Coordinator at WPI. By reaching out to them, the team was able to get in touch with the first potential teacher for the project.

After the team investigated the core curriculum standards of Massachusetts further, it was determined that a different educational program would have to be explored in order for the objective of the project to be met. The incorporation of 3D printing and the material developed had to be easily incorporated and not take away from what the students were supposed to be learning in their class. The team decided to meet with the Project Lead the Way Manager at

WPI. The PLTW manager allowed us to send out an email describing the project to the PLTW community to see if there was any interest. Teachers B and C were put in contact with the team through the email.

### **3.1.1 Interview Teacher A**

Teacher A, was a local middle school engineering science teacher and was the first teacher the STEM Education Coordinator put the team in contact with. There was an initial meeting to introduce ourselves in person and speak about objectives for both our project and the teacher's learning objectives for the students. Initially, it was felt that Teacher A may have been a good fit for working on this project. After further discussion and research on the common core curriculum in Massachusetts, it was found that the the material that the team wanted to cover was not in the standards for the middle school students. Students in Massachusetts public schools do not tend to reach physics and more higher level STEM classes until high school. Considering that the objective of the project was to integrate 3D printing into classes where basic physics and engineering principles were learned, Teacher A was not the best match for this project. Proper communication procedures were made to make this known to the teacher before continuing to look for a teacher that matched the objective of the project.

### **3.1.2 Interview Teacher B**

Teacher B, was a local high school PLTW teacher teaching Principles of Engineering. The Principles of Engineering course is described above in the approach section of the paper. The initial meeting was structured much like the first where it was used to introduce the team and project to the teacher to see if the objectives of the project and of the class were compatible. This teacher was a suitable fit for this project. The students Teacher B was teaching were in the class to learn specifically about engineering and were at a high enough level of education, that they could benefit from the incorporation of the project in their class. Teacher B had no prior 3D printing experience, but was interested in learning more about how it worked During this interview there was also further discussion of what the objectives of the class were and different sections of the curriculum that needed to be taught and where 3D printing could be of use. These sections included Statics and Forces as well as Materials. Teacher B was the primary collaborator for the IQP.

### **3.1.3 Interview Teacher C**

Teacher C was also a local high school PLTW teacher teaching Introduction to Engineering Design. The Introduction to Engineering Design course is described above in the approach section of the paper. This initial meeting was structured the same way as the previous meetings described above. Teacher C was also considered a suitable teacher to work with on this project because they had a class that could benefit from the lesson plans being developed as well as prior 3D printing knowledge. This teacher wanted to make a lesson plan to teach students how to use a MakerBot 3D printer. This would include which settings to use for different materials, orientation of parts on the print bed, and general MakerBot Desktop Software use. This tutorial would be used in conjunction for the “Puzzle Cube” project for their class which can be seen in the appendix. Only one meeting occurred with this teacher and there was no testing of the curriculum. However, the lesson plan was still created for a tutorial on 3D printing using a MakerBot.

## **3.2 Tested Modules**

This section contains brief overviews of each the procedures taken to develop each of the tested modules. These modules include 3D Printing Introduction and Demo, Truss Analysis Introduction, Truss Analysis Project Part 1, and Truss Analysis Project Part 2 - Design. These modules are each discussed in terms of their curriculum requirements, creation, presentation, and evaluation.

### **3.2.1 3D Printing Introduction and Demo**

#### **3.2.1.1 Identification of Curriculum Requirements**

The main objective of the IQP was to integrate 3D printing into pre-existing curriculum. A meeting with teacher involved was set up to gauge how useful 3D printers could be in the class being taught. Potential projects that could utilize 3D printing were discussed. This was done while keeping in mind that the focus of the project was not on 3D printing, but using it as a tool to supplement the material being learned in the engineering course. It was established that although the focus of the project was not just teaching students about 3D printing and how to use it, it was necessary to create a module introducing the students to 3D printing, how it worked, applications. A live demo of 3D printing and how to use a 3D printer was also requested.

#### **3.2.1.2 Creation of Lesson**

This module was created using previous knowledge of 3D printing and experience building 3D printers.

#### **3.2.1.3 Presentation of Lesson**

This lesson plan was developed and tested in a classroom setting. The students were shown a slide show and 3D printed objects were passed around.

#### **3.2.1.4 Evaluation of Lesson**

This lesson had the opportunity to be evaluated in a classroom environment. Unfortunately for this lesson, there was a miscommunication of the objective in terms of when the demo would happen. It was expected by the team to happen at a later date, and the teacher wanted it to be coupled with the introduction to 3D printing. The lesson plans have now been modified to meet that requirement. Other than that miscommunication, according to the surveys and interview with the teacher, the lesson was effective and useful to the students as expressed in the discussion section.

### **3.2.2 Truss Analysis Introduction**

#### **3.2.2.1 Identification of Curriculum Requirements**

After meeting with the teacher regarding another lesson plan, one subject area that needed to be taught was Statics. The students could be taught the basics of truss analysis. It was determined that this would be useful in giving the students more experience with free-body diagrams. As per the request of the teacher, a module on the analysis of trusses was developed. Another request made was that a bridge would be broken in order to show the students a direct application to the analysis done.

#### **3.2.2.2 Creation of Lesson**

This module was created using previous knowledge of truss analysis from Statics class. The textbook “Engineering Mechanics: Statics” and notes from this class were used to verify all of the information given in the modules to ensure that the students were taught in a manner that was the most useful and easy to understand [4]. The module introduced the students to the method of joints used for truss analysis.

### **3.2.2.3 Presentation of Lesson**

This lesson plan was presented in powerpoint format. The analysis of a bridge was shown and a demo of bridge testing was given to show the students a direct application of the analysis.

### **3.2.2.4 Evaluation of Lesson**

This lesson had the opportunity to be evaluated in a classroom environment after presentation via survey. This lesson plan was viewed as slightly harder to understand than the previous lesson plans discussed. However, this module was also still viewed as useful and interactive because of the breaking of the bridge at the end showing where the bridge deformed and being able to compare the results to the calculations done during the presentation.

## **3.2.3 Truss Analysis Project Part 1**

### **3.2.3.1 Identification of Curriculum Requirements**

After consulting the teacher, the PLTW truss design project was seen as a decent candidate for a project where 3D printing could be incorporated. This design project is a generic project within the PLTW curriculum, however, it was determined that modifying it to use 3D printer, may bring added benefits the students.

### **3.2.3.2 Creation of Lesson**

This module was created using the previously existing PLTW project with slight modification. Instead of having the students build popsicle stick models of certain types of trusses, they were walked through using Inventor CAD software to model the bridges and analyze them in the software after performing calculations by hand. Previous knowledge of how to use Inventor was needed for this part of the project because Inventor was the CAD package available to students at the high school.

### **3.2.3.3 Presentation of Lesson**

This lesson plan was presented in powerpoint format. During the class, students were aided with their CAD and analysis of the trusses. By using CAD, the students were able to send the files to be printed.

### **3.2.3.4 Evaluation of Lesson**

This lesson had the opportunity to be evaluated in a classroom environment after presentation

via survey. This lesson plan was viewed as slightly harder for some of the students that had not previously used Inventor.

### **3.2.4 Truss Analysis Project Part 2 - Design**

#### **3.2.4.1 Identification of Curriculum Requirements**

The second part of the design project that was requested involved showing the students various different types of trusses. This lesson plan was intended to guide the students to think about how certain designs performed under different loads, how forces are distributed amongst the members of a truss, and efficiency in terms of use of material versus how much weight the bridge can sustain.

#### **3.2.4.2 Creation of Lesson**

This module was created using various online resources pertaining to bridge design including the civil engineering and architecture website <http://www.skyciv.com>. Other academic sources also include “Engineering Mechanics: Statics” [4].

#### **3.2.4.3 Presentation of Lesson**

This lesson plan was presented in powerpoint format. During the class, students were encouraged to ask questions about the bridges and were reminded of key points about each design presented. After the presentation was given, the students were broken up into teams. First each group member would come up with a design for a bridge that could be presented to their team for evaluation. The bridge designs for each team were determined through the use of a design matrix. Students were then instructed to input their designs into Inventor so that the designs could be 3D printed. The students were aided in their modeling by the instructors.

#### **3.2.4.4 Evaluation of Lesson**

This presentation was well put together and required more research due to the fact that neither one of the IQP students were Civil Engineering/ Architecture majors. The truss designs, however, could be studied to determine the better designs through the knowledge of Statics, which both IQP students had taken previously.

### **3.3 Untested Modules**

This section contains brief overviews of each the procedures taken to develop each of the untested modules. These modules include General Free Body Diagrams, Introduction to Materials, Materials Testing, and How to Use a MakerBot. These modules are each discussed in terms of their curriculum requirements, creation, presentation, and evaluation.

#### **3.3.1 General Free Body Diagrams**

##### **3.3.1.1 Identification of Curriculum Requirements**

In order to ensure that the lesson plans would be of most use to both teachers and students, a teacher was contacted, and the required core subjects for the class being taught was discussed. Each of the lesson plans developed were made to fit directly into the Project Lead the Way Principles of Engineering curriculum. Several meetings took place. The first lesson plan developed was based on the needed requirement for the students to learn free-body diagrams. This subject is one of the core requirements for the Principles of Engineering class, but is more challenging to make the subject manner more interesting.

##### **3.3.1.2 Creation of Lesson**

This module was created using various different sources. University Physics with Modern Physics was referenced in the development of this lesson plan[5]. However, other sources were used as well such as “The Way Things Work”, a science book geared more towards youth[6]. This source was used to help present the material in a manner easier for high school aged students to understand.

##### **3.3.1.3 Presentation of Lesson**

This lesson was developed. However, this module was not tested in a classroom environment because of time constraints for moving forward with the students’ learning.

##### **3.3.1.4 Evaluation of Lesson**

This lesson did not have the opportunity to be evaluated in a classroom environment. However, the lesson plan was evaluated by the teacher involved in the development of the lesson plans for the students. This lesson plan was seen as a useful, implementation that made the process of drawing free - body diagrams more interesting and interactive.



### **3.3.2 Introduction to Materials**

#### **3.3.2.1 Identification of Curriculum Requirements**

The module on an introduction to Material Science that was requested involved showing the students the basics of Materials Science. This lesson plan was intended to guide the students to think about different types of materials and why they are used for certain applications.

#### **3.3.2.2 Creation of Lesson**

This module was created through the reference of “Materials Science and Engineering: An Introduction 9th Edition” which is the book required for the Introduction to Material Science course at WPI [18]. Prior knowledge from taking the “Introduction to Material Science” course at WPI was also used in the creation of this module.

#### **3.3.2.3 Presentation of Lesson**

This lesson was developed. However, this module was not tested in a classroom environment because of time constraints for submission of the IQP and scheduling conflicts due to the break schedules of the school the team was presenting at.

#### **3.3.2.4 Evaluation of Lesson**

This lesson was unable to get feedback from the teacher or the students.

### **3.3.3 Materials Testing**

#### **3.3.3.1 Identification of Curriculum Requirements**

The module on Material Science that was requested involved showing the students the basics of materials testing. This lesson plan was intended to teach the students how materials tensile tests work, the generation of a stress strain curve of a material from these tests, and how to interpret the curve to determine key properties of materials being tested.

#### **3.3.3.2 Creation of Lesson**

This module was created through the reference of “Materials Science and Engineering: An Introduction 9th Edition” [18]. Prior knowledge from taking the “Introduction to Material Science” course at WPI was also used in the creation of this module.

#### **3.3.3.3 Presentation of Lesson**

This lesson was developed. However, this module was not tested in a classroom environment because of time constraints for submission of the IQP and scheduling conflicts due to the break schedules of the school the team was presenting at.

#### **3.3.3.4 Evaluation of Lesson**

This lesson was unable to get feedback from the teacher or the students.

### **3.3.4 How to Use a MakerBot**

#### **3.3.4.1 Identification of Curriculum Requirements**

The module on how to use a MakerBot that was requested by Teacher C involved showing the students the basics of how to use a MakerBot from temperature settings to placement of . This lesson plan was intended to teach the students how materials tensile tests work, the generation of a stress strain curve of a material from these tests, and how to interpret the curve to determine key properties of materials being tested.

#### **3.3.4.2 Creation of Lesson**

Reference manuals for the MakerBot Desktop software were used to create this lesson plan as well as previous knowledge of how to use the software.

#### **3.3.4.3 Presentation of Lesson**

This lesson was developed. However, this module was not tested in a classroom environment because of time constraints for submission of the IQP and scheduling conflicts due to the break schedules of the school the team was presenting at.

#### **3.3.4.4 Evaluation of Lesson**

This lesson was unable to get feedback from the teacher or the students.

### **3.4 Survey**

This section covers the procedures taken to give a survey to the students for the evaluation of the lesson plans developed. The procedure includes creation of the survey on Survey Monkey, IRB Approval, and the administration of the survey.

### **3.4.1 How Survey Was Created**

This survey was created purely for feedback purposes for the project. The survey had basic questions that the team wanted to be answered in order to help improve the curriculum for future iterations. This survey was created using Survey Monkey. This tool allowed for the submission of questions for general feedback ratings such as strongly disagreeing or agreeing to statements as well as short answer questions. This tool also allowed the team to administer the survey online and collect the data while keeping the results anonymous for the privacy of the students taking the survey.

### **3.4.2 Institutional Review Board (IRB) Submission and Approval**

In order to administer surveys for any project at WPI, the survey must be approved or exempt from the IRB. This process involved filling out the required forms for IRB approval found on the WPI IRB webpage. These forms were used to give the IRB information regarding why the survey is being created and the risk level of the survey. This approval also required the submission of a draft of the methods section of the IQP report as well so they could get a better idea of what the project was about. After review, the survey received educational exemption.

### **3.4.3 Administration of Survey**

This survey was administered via a SurveyMonkey link sent to Teacher B. All data was collected and secured the privacy of those answering the survey because it was completely anonymous. The data was collected and analyzed. This data will be further discussed in the results and discussion sections of the report.

## **4 Results**

Lesson plans were developed and incorporated into class and project work. The PLTW syllabus allowed some flexibility while defining topics that needed to be covered. After consulting teachers, particular parts of the course were marked for the incorporation of 3D printing. The included subjects are described in the sections below.

## 4.1 Tested Modules

This section contains brief overviews of each the implementation of the tested modules. These modules include the 3D Printing Introduction and Demo, Truss Analysis Introduction, and Truss Design Project. These modules are each discussed in terms of their curriculum requirements, creation, presentation, and evaluation. The requirements for the lesson plans were taken directly from the PLTW curriculum[15].

### 4.1.1 Statics

#### 4.1.1.1 Required Material Covered for Satisfactory Lesson Plans

- Laws of Motion describe the interaction of forces acting on a body.
- Structural member properties including centroid location, moment of inertia, and modulus of elasticity.
- Applied forces are vector quantities with a defined magnitude, direction, and sense, can be broken into vector components.
- Forces acting at a distance from an axis or point attempt or cause an object to rotate.
- In a statically determinate truss, translational and rotational equilibrium equations can be used to calculate external and internal forces.
- Free body diagrams are used to illustrate and calculate forces acting upon a given body.

#### 4.1.1.2 Implementation

The lesson plans for this section of Principles of Engineering was split up into five different lesson plans designed and presented for the high school students.

##### Fused Deposition Modeling (FDM)

- Fused Deposition Modeling also known as FDM is a form of 3D printing that involves putting down layers of material and building parts bottom up.



Figure 1: Introduction to 3D printing Sample Slide

#### 4.1.1.3 3D Printing Introduction and Demo

A lecture on different types of 3D printing was given to the students to introduce them to the technology. The presentation covered topics such as the various types of 3D printing, how they work, and applications. Figure 1 above shows a sample slide from this presentation.

This lecture was also a segway to introducing future plans for projects with students. A more detailed description of the original lesson plan can be found in the Introduction to 3D Printing section of the appendix.

#### 4.1.1.4 Truss Analysis Introduction

Instructed students on how to calculate the forces in a truss when a point load is applied. The calculations were done to figure out where the failure points of the truss would occur. After the presentation was given, there was a live demo of breaking 3D printed trusses that were the same model as the truss ana-

lyzed in the presentation. The truss ended up failing at the members that were undergoing the most stress according to the calculations done in the presentation. After completion of the truss breaking demo, a 3D printing demo was done as well. The presentation covered topics such as the various types of 3D printing, how they work, and applications. Figure 2 to the above shows a sample slide from this presentation.

A more detailed description of the original lesson plan can be found in the Truss Analysis section of the appendix.

#### 4.1.1.5 Truss Design Project

The truss design project is a PLTW project that is part of the Principles of Engineering curriculum. The standard curriculum has the students make bridges out of popsicle sticks and glue. Template bridges are constructed and tested first to give students an idea of how different bridge designs compare to each other in terms of how much material is used and how much force is applied. They then complete calculations of forces on the members of trusses using the data collected from the breaking of the trusses. After this exercise the lesson plan has them design a

Step 4: Set up Separate Free Body Diagrams for Each Joint  
Joint A

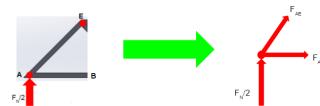


Figure 2: Truss Analysis Introduction Sample Slide

truss using the knowledge they learned.

The implementation of this project was modified to include 3D printing and CAD tools. Instead of having the demo trusses made from popsicle sticks and glue, the students created CAD models of the trusses in Autodesk Inventor and the bridges were 3D printed. Before the students broke the trusses, they were also taught how to use stress analysis tools in Inventor. The students were given a maximum deflection of the truss members given a point load applied at the center of each truss. The maximum deflection indicated a failure in the structure. The students were then able to get a rough estimate of how much force the truss would be able to take. Once the trusses were printed for the next lesson, they were broken and analyzed to see where they failed and how much force was applied when the truss failed. The students then took down the data for the weight of each truss and the force applied at failure to use them in their calculations. WPI instructors then also helped students calculate the forces on the members of the trusses. A sample slide from this presentation can be seen in figure 3 to the right. A more detailed description of the original lesson plan can be found in the Truss Analysis section of the appendix. A more detailed description of the lesson plans can be found in the Truss Project Part 1 and Truss Design sections of the appendix.

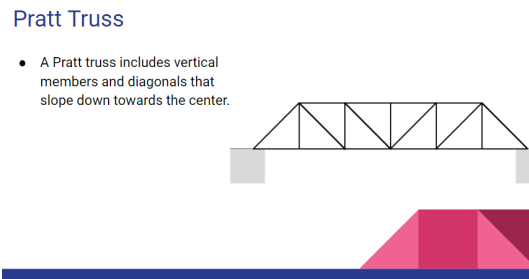


Figure 3: Truss Design Sample Slide

## 4.2 Untested Modules

### 4.2.1 Materials

The requirements for the lesson plans were taken directly from the PLTW curriculum[15].

#### 4.2.1.1 Required Material Covered for Satisfactory Lesson Plans

- Materials are the substances with which all objects are made.
- Materials are composed of elements and are categorized by physical and chemical properties.

- Materials consist of pure elements. Compounds and mixtures and are typically classified as metallic, ceramic, organic, polymeric, and composite.
- Material properties including recyclability and cost are important considerations for engineers when choosing appropriate materials for a design.
- Material selection is based upon mechanical, thermal, electromagnetic, and chemical properties.
- Raw materials undergo various manufacturing processes in the production of consumer goods.

#### 4.2.1.2 Introduction to Materials

The objective of this lesson plan was to introduce the students to the basics of material science and get them to think about why certain materials are chosen for different applications in engineering. This lesson was put in powerpoint presentation format. The slides in this presentation included covering the four main categories of materials, ceramics, metals, polymers, and composites. The presentation went through properties, examples and appli-

cations of each type of material. At the end of the lesson there is an exercise with questions to check the understanding of the students of the lesson covered. These questions include for example “What material category does wood belong to?” and an exercise that says “Choose an item that you use everyday and list which materials make it up and why you think those materials are chosen?” A sample slide of the Introduction to Materials section, can be seen in figure 4 above. The full lesson plan can be seen in the Introduction to Materials section of the appendix.



Figure 4: Introduction to Materials Sample Slide

#### 4.2.1.3 Materials Testing

The objective of this lesson plan is to introduce the students to how the tensile testing of

materials is performed and the generation of a stress-strain curve from this process. The presentation also covers how to interpret the stress-strain curve to get important values such as yield strength, ultimate tensile strength, and young's modulus.

These terms are also introduced and covered with an explanation of elastic versus plastic deformation as well. With this presentation there is also a hands on lesson with 3D printed components showing the difference between elastic and plastic deformation. A sample slide of this presentation can be seen above in figure 5. The full lesson plan can be seen in the Materials Testing section of the appendix.

#### Tensile Testing

Tensile Testing - a test where a material specimen is pulled on both sides lengthwise until the point of fracture.

Typically, these specimens are in the shape of a "dog bone" so that the deformation of the specimen is confined towards the narrow center region.

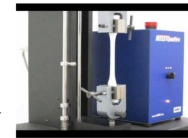


Figure 5: Materials Testing Sample Slide

## 4.3 3D Printing

### 4.3.0.4 Required Material Covered for Satisfactory Lesson Plans

- Show students how to use the MakerBot Desktop software from exporting the part to an STL to printing.
- Teach students about importance of part orientation, part spacing, and support material when 3D printing parts.
- Make sure that the information given to the students is enough to independently use a 3D printer, but is not presented in a manner that is too overwhelming to the students.



#### 4.3.0.5 MakerBot Desktop 3D Printing Tutorial

The objective of this lesson plan was to help guide students in using the MakerBot Desktop 3D printing software. The tutorial begins with exporting a model in Inventor as an STL and loading it into the MakerBot Desktop software and putting it on the build plate.

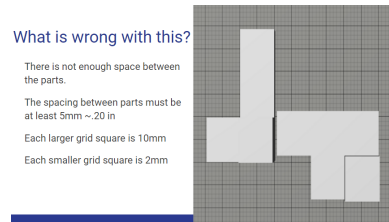


Figure 6: MakerBot Desktop Tutorial Sample Slide

The different buttons within the program are also explained such as the buttons for moving a part and rotating it about different axes. Different settings are then explained such as extruder temperature, bed temperature, and supports. A sample slide from this lesson can be seen above in figure 6. The full lesson plan can be seen in the How to 3D Print section of the appendix.

### 4.4 Evaluation of Tested Modules

#### 4.4.1 Survey Results

##### 4.4.1.1 Student Survey Responses

The responses in this section refers to the percentage of people that responded in a certain way (i.e. Strongly Agree or Neutral) for each statement given in the survey. These statements are listed below.

#### Student Survey Statements:

1. I learned new information about 3D printing.
2. I was inspired to think creatively about 3D printing.
3. The incorporation of 3D printing was helpful in understanding engineering concepts.
4. The incorporation of 3D printing stimulated your interest in engineering.

5. The lesson plans were helpful in terms of understanding the material.
6. The hands on exercises aided in the understanding of the subject material.
7. I would like to see 3D printing incorporated into my other engineering classes.
8. I would like to see 3D printing incorporated into my other non-engineering classes.
9. The material was presented in a fashion that was easy to follow.
10. The overall experience with the visitors was positive.

The statements are grouped into sections that represent specific aspects of the project. These sections are curriculum, style, and interest. Further explanation of these sections and their results are available in the discussion section.

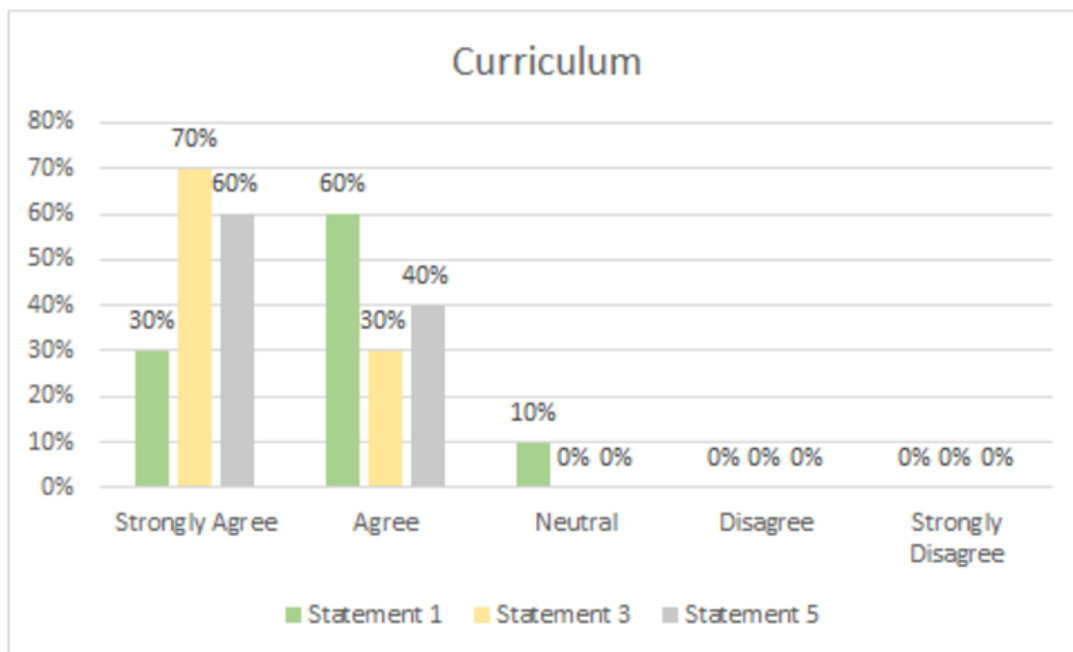


Figure 7: Survey Responses: Curriculum

The curriculum section had a 53.3% strongly agree (SA), a 43.3% agree (A), and a 3.3% neutral (N) response as seen above in figure 7. This suggests that the students overall believed that the content was helpful and understandable to them. The only neutral point in the section was about the statement “I learned new information about 3D printing.” which suggests that we may not have been presenting the state of the art, or that the student has prior advanced

knowledge of 3D printers.

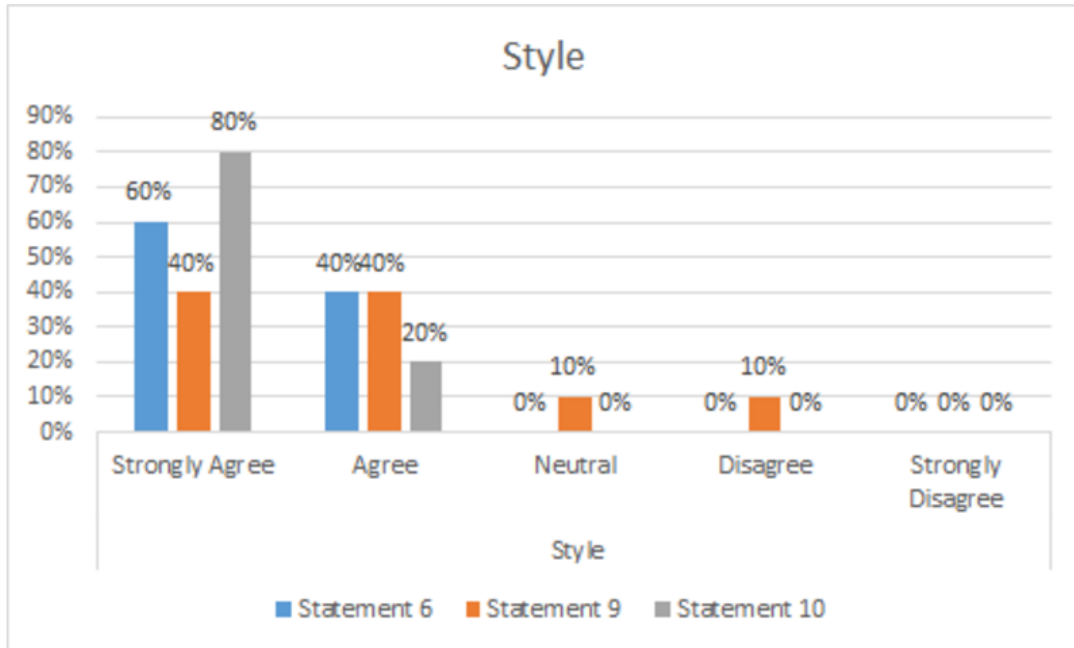


Figure 8: Survey Responses: Style

The style section had a 60% SA, a 33.3% A, 3.3% neutral (N), and 3.3% disagree (D) response as seen above in figure 8. This suggests that the students overall enjoyed the presentations and demonstrations. The two responses that were N and D were both for statement 9 “The material was presented in a fashion that was easy to follow.” This suggests that our slides may need revision in pace and complexities.

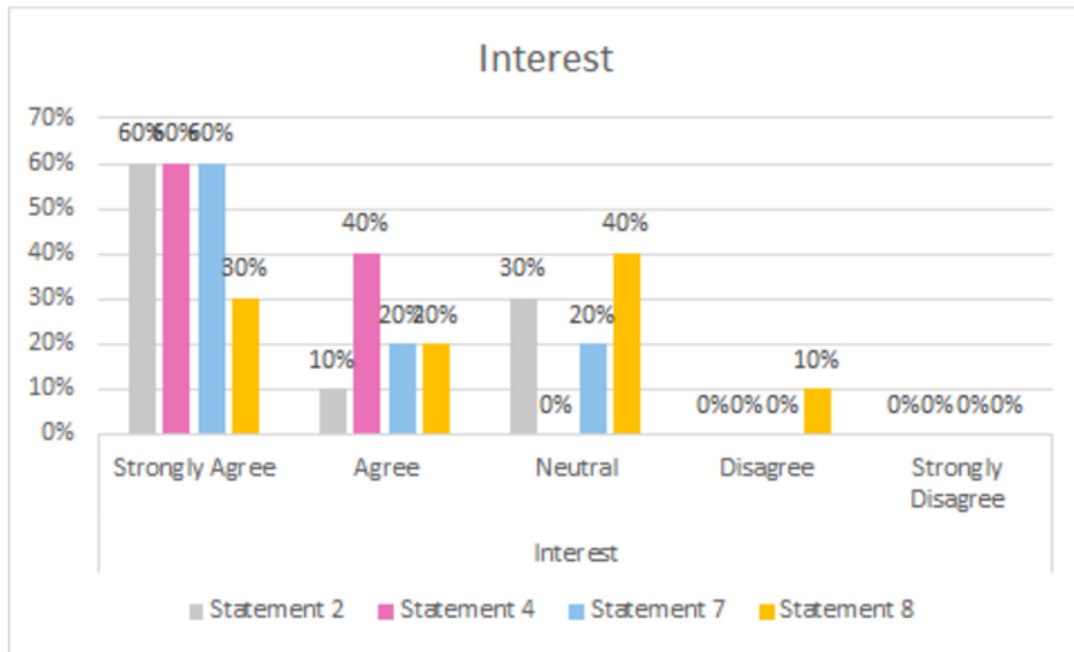


Figure 9: Survey Responses: Interest

The interest section had a 52.5% SA, a 22.5% A, 22.5% neutral (N), and 2.5% disagree (D) response as seen above in figure 9. This would suggest that there is interest in 3D printing in the classroom. A further breakdown of this section reveals that most of the negative responses come to statement 8, “I would like to see 3D printing incorporated into my other non-engineering classes.”

#### 4.4.1.2 Teacher Responses

The first question asked the teacher to identify any other topics that they would like to be covered in future curriculum.

**Question 1:** Are there any additional engineering topics that you would have liked for us to have taught pertaining to 3D printing?

**Answer:** Yes, I was hoping to integrate it into material testing with stress and strain, but we did not have time.

Materials testing was a section that we had discussed with the teacher but were not able to test.

**Question 2:** Can you suggest any other projects where 3D printing would be beneficial?

**Answer:** The students loved building the trusses with the 3D printer. It would also be nice to print “dog bones” that the students could test and analyze during their material testing unit.

**Question 3:** Suggest any improvement in the lesson plans:

ex: I wish they could have given more instruction on CAD.

**Answer:** I had seen a power point with superheroes in it that described free body diagrams, but it was never presented. I think that would have been really cool and connected with the students. I think that if this were to happen again in the future, it would be helpful for the WPI students and I to actually work through a problem together, because some of the students were confused from two different methods of analysis being introduced. The method of joints does not seem so overwhelming for people like you and me since we have done it several times before. It was very overwhelming for the students due to their math skill level and the number of steps. As a result, I approach it a bit differently from how you two did. Nothing wrong, just different.

**Question 4:** Is there anything that we could have done to make the process of incorporating the lesson plans easier?

**Answer:** We struggled a bit with communication. Perhaps talking on the phone would have been helpful or actually writing out lesson plans (or more minute-by-minute expectations) so that we were more clear about what we were doing on both ends.

**Question 5:** How could we make the lesson plans better communicate their objectives in an understandable manner?

**Answer:** A good teaching model is to tell the students what your expectation is for the class and what your agenda is for the presentation at the beginning of the presentation. You saw me kind of walk them through an agenda at the beginning of each class. That gives them kind of a road map of where we are going. Otherwise, I thought you did fine.

**Question 6:** Is there any way that we could have improved our methods of communication throughout the project?

**Answer:** Perhaps talking on the phone would have been helpful or actually writing out lesson

plans (or more minute-by-minute expectations) so that we were more clear about what we were doing on both ends.

The raw survey results can be seen in the Survey section of the appendix.

## **5 Discussion**

### **5.1 Challenges to Project**

This project contained many challenges, but through proper research and planning many of these challenges were overcome.

#### **5.1.1 Did we meet our objective?**

Our first challenge was to meet the objective of the project which we did. The objective was to integrate 3D printing and 3D printed parts into lesson plans that can be used to teach key engineering concepts in engineering classes in grades K-12. This was accomplished mainly for high school students (9th - 12th grade) as there was a focus in Project Lead the Way curriculum as it was the easiest to integrate to.

#### **5.1.2 Was the curriculum expandable?**

Making the curriculum expandable to other teachers and schools was also a primary focus. This was able to be accomplished by making the curriculum fused with the curriculum and projects of PLTW. This is a good way to let PLTW teachers continue to use the projects that they are already familiar with while giving them the ability to add new content via the use of 3D printing.

#### **5.1.3 Were the lesson plans easily incorporated into classes?**

The curriculum and projects were an easy fit for our experience as PLTW uses a flexible curriculum for its projects. With communication with the teacher, it was simple to modify lesson plans and projects when the curriculum's objectives are broadly stated, and without narrow restriction for implementation.

## 5.2 Analysis of student survey results

The responses that we received from students were decidedly positive in that 87 % of all of the responses either agreed or strongly agreed with the statements made in the survey, inciting a positive review.

The survey questions were broken down into sections including, the quality of the content in the curriculum, the quality of style of the presentation that the students were given, and a section based purely on the interest in the content by the students.

The curriculum section is represented by statements 1,3, and 5 given respectively as “I learned new information about 3D printing.”, “The incorporation of 3D printing was helpful in understanding engineering concepts.”, and “The lesson plans were helpful in terms of understanding the material.”.

The style section is represented by statements 6,9, and 10 given respectively as “The hands on exercises aided in the understanding of the subject material.”, “The material was presented in a fashion that was easy to follow.”, and “The overall experience with the visitors was positive.”

The interest section is represented by statements 2, 4, 7, 8 given respectively as “I was inspired to think creatively about 3D printing.”, “The incorporation of 3D printing stimulated your interest in engineering.”, “I would like to see 3D printing incorporated into my other engineering classes.”, and “I would like to see 3D printing incorporated into my other non-engineering classes.”

The responses for style and curriculum are the most sensitive to our project as it is a reflection of our efforts to the students. These sections are still separate though as one is based more on how well the content was able to help the students (curriculum section) and the other section (style) was more descriptive as to how well we presented the information. The interest section is to assess student interest in 3D printing in school.

### **The written questions given to the students were as follows:**

Are there any additional engineering topics that you would have liked to learn?” “Can you suggest any other projects where 3D printing would be beneficial? (This can include projects that you have already done.)” “Suggest any improvement in the lesson plans, ex: I wish they could have given more instruction on CAD.”

The first two questions were meant to bring out any creative thought that the students would

like to share with us about how to further implement 3D printing into their curriculum. The last question was meant as a way for the students to give any suggestions that they saw fit for the program.

The majority of the written responses from the students consisted of null answers such as “no” or “nothing” but a few were valuable.

The first statement brought mention twice to using more CAD/software. While these were the only different responses it suggests that further knowledge in CAD is desired, which will be brought up more in the analysis of written response three.

### **The second statement yielded multiple valuable answers from the students:**

A Rube Goldberg Machine project was brought up three times. A Rube Goldberg Machine is a series of mechanical/chemical interactions of components that completes a objective at the end[16]. The implementation of 3D printing into this project could be using the 3D printer to print some number of elements in the system. It could also be used to prototype before an actual permanent part is made. There are many possibilities for 3D printing in this project, and the creation of such a machine could easily be incorporated into the simple machines section of the syllabus for POE.

A suggestion that was brought up twice was to use the 3D printer to make printed objects that are the subject of a question/project. These objects would aid in the understanding more complex models. While this seems simple, it could be very helpful for the spatial development of students. This could be implemented in not only engineering courses, but also math classes that are covering area, surface area, or volume of complex shapes. It could be used to print the “disks” and “slices” of shapes that are produced from taking integrals.

One response was aimed at using the 3D printer to make different shaped cars. Having a universal body and then printing a shell that can fit onto the body of a car could be useful for prototyping and visualization. Every student would use the same parts for the body of the car, except for their customized shells. This can be valuable in a physics class when teaching about aerodynamics as it would open up the realm of creativity to students and take out the labor and human error from constructing the parts (assuming proper use of the machine).

The final valuable response mentioned that doing more building structural tests would be



beneficial. There are limits to the type of testing you can do as plastic and metal are ultimately different materials and the differences in these materials will cause different behavior in the parts. For the most part ,however, the weak points will still be identical so it is still very much a valid method of testing.

**The third statement yielded multiple valuable answers from the students:**

It was mentioned twice that the information should be made more easy to follow. This could be from subtle differences in the teaching style between the teacher’s approach and our team’s approach. Having one approach is a revision we would like to make and recommend to others. Starting presented material with a daily overview may also have been beneficial as it would have set the pace for the day so when topics changed it would not have caught the students off guard.

Two responses mentioned that there should be more instruction with CAD software, if it was going to be used. This is a difficult grey area as we don’t want to always have to incorporate CAD into say a math class just because they would use CAD for one class, but it could definitely be useful to have a handbook or at least a video of a possible solution to teach the students the basic features and functions of CAD software.

One response was that they did not like our use of presentations to teach. This recommendation holds academic value of not using presentations to lecture this type of material. Instead there could be more lab based instruction.

There were three students that had positive outlooks on our approach and said that no revisions needed to be made. While this feedback does not give any revisionary input, it is still valuable as it supports the value of our current curriculum.

### **5.3 Analysis of teacher survey results**

Overall Teacher B had a positive experience with the use of the lesson plans and utilization of 3D printing. Teacher B enjoyed that their students had an interactive project which engaged them in the topic.

The responses from the teacher were valuable towards how the lesson plans can be improved. Communication of the class objectives was at times a problem in the lesson plans, however it can be avoided by making the lesson plans with a minute-by-minute objective. There will also be a need for more interactive examples during the introduction of new materials. Teacher B

recommended one example per objective, before there is any type of cooperative project. This approach also makes sure that all of the approaches from the students are taught the same way.

Teacher B had plans to use 3D printing to teach stress and strain. However, the lesson plans created, were not tested due to time constraints.

## **5.4 Improvements to Lesson Plans**

The lesson plans biggest deficiency was in its lack of incorporation of approach. There needed to be examples that involved students, so that they had time to ask questions, learn, and be sure of what they learned. A flowing lesson plan that involves the student in examples and builds comprehensively towards an objective is the ideal lesson plan.

## **5.5 Finding teacher/ program that matches objective**

A vital step was finding the program that would best support STEM content. More specifically there is an emphasis on finding curriculum guidelines in the education of technology and engineering. Whether the program be an in class activity or an extracurricular activity came down to timing. The programs that were initially in the works was MA Common Core, Project Lead The Way (PLTW), and FIRST robotics teams.

### **5.5.1 Common Core vs Extracurriculars vs PLTW**

The three programs would have very different needs and would be used for different matters. The in class would have a much more adherent guide as it would be based off of existent curriculum guidelines where as an extracurricular there could be any for of education. (Common core does not have enough engineering classes for our purposes) Common Core is an accessible option to Massachusetts schools as they are starting to convert to these standards. While this does meet an objective of being expandable it falls short in flexibility. With limited STEM content there is not much to build off of as far as lesson plans go. Even worse there is a strict allowance for what is in the classroom with Common Core which makes incorporating new methods into the system difficult[8]. The consideration of FIRST Robotics Teams as an extracurricular stemmed from the continued efforts of local teams to learn and promote STEM education. While this has both the interest in STEM and the flexibility for a new style of education there was a time conflict. FIRST teams' most busy time of the year is during their 6 week build season starting in

the winter. It just so happens that that time period our group would be presenting information would be in the middle of their build season. This would be unacceptable for our purposes so it was decided that this should be left up for future consideration, but not for current investigation. PLTW has curricula that met our objectives and were flexible enough to incorporate them.

PLTW uses a very flexible curriculum basis to define objectives in Science, Technology, Engineering, and Math. PLTW offers a wide variety of classes and shares them between schools. A class has standard objectives which enables expansion of our created lesson plans as they are modifications to a class's lesson plans. This gives many teachers the opportunity to utilize 3D printing lesson plans within their current classes. As PLTW expands it enables further and further potential for our lesson plans to be used by more and more teachers.

### **5.5.2 IRB Approval**

IRB Approval is a process that certifies the intent of a project. This project used a survey with high school students, requiring the IRB to approve our survey to evaluate its risk level and make sure that did not disclose any of the participants' personal information. This project received an educational exemption for the survey. IRB Approval is mandatory before a survey is given.

## **5.6 Further work to be done on project**

The lesson plans would be the first update to be made. Refer to the "Improvements to Lesson Plans" section for more information on this. Once the lesson plans fulfill the requirements of particular sections, additional topics can be researched and other projects in PLTW can be assessed for their viability to have 3D printing applied to them.

## **6 Conclusion**

- Objective met
- Curriculum was expandable through the incorporation in PLTW
- Based on survey results, Teacher B viewed the lessons as fitting well into current curriculum
- Based on survey results, Teacher B and majority of students found the developed content useful

## 6.1 Challenges of Project

- Finding Teacher/Program that met the objectives of the project
- Communication between project team and teacher
- Gaining IRB Approval

## 6.2 Further work to be done

- Further testing and improvement of existing lesson plans
- Creation of more lesson plans including those suggested by Teacher B and sampled students

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start appendix

## A Appendix

### A.1 Authorship


Section	SC	MM
Abstract	X	
Introduction	X	
Background	X	
State of the Art	X	
Approach	X	
Methods	X	
General Results	X	
Survey Results		X
Discussion		X
Conclusion	X	X
Appendices and Bibliography	X	X

Table 1: Section Leads

### A.2 Presentations


#### A.2.1 Introduction to 3D Printing

### 3D Printing!



### What is it?

- A process for making a physical object from a three-dimensional digital model. This is done additively through the layering of material.




### Different Types

FDM - Fused Deposition Modeling  
SLA - Stereolithography  
Many more!

### Fused Deposition Modeling (FDM)

- Fused Deposition Modeling also known as FDM is a form of 3D printing that involves putting down layers of material and building parts bottom up.

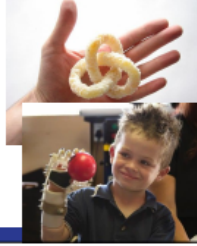


## Stereolithography (SLA)

- Builds 3D models out of photo polymers through utilizing UV cured resins. These printers were the first form of additive manufacturing.

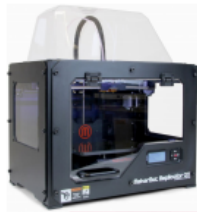


## What is it used for?



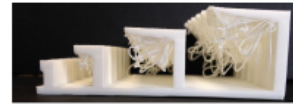
## What are you using?

- Makerbot Replicator 2x - A FDM machine
- MakerBot Desktop Software



## Key Concepts

- Part orientation
- Overhang
- Use of support material
- Print settings



# Demo Time!



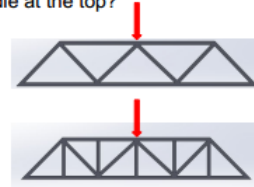
## A.3 Truss Analysis

### Truss Analysis

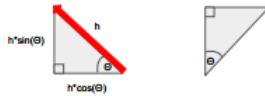


Which can withstand more force when a point force is applied in the middle at the top?

Bridge 1  
or  
Bridge 2?



Summing forces when given force at angle



\*\* Note that  $h \sin(\theta)$  is not always the y component and  $h \cos(\theta)$  is not always the x component!

Use  $h \sin(\theta)$  to find the component that is opposite from the angle given.

Use  $h \cos(\theta)$  to find the component that is adjacent to the angle given.

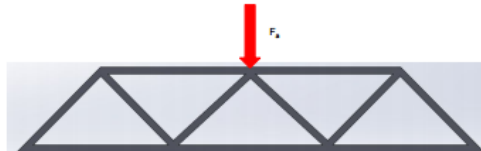
Steps for Truss Analysis

- Where is force being applied?
- Where are the reaction forces?
- Label joints
- Draw Free Body Diagrams for each joint
- Label Forces on Original Diagram

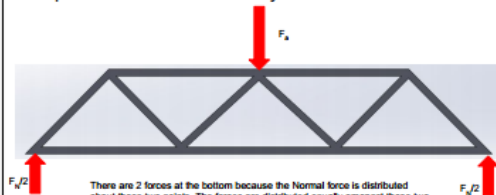
Example 1



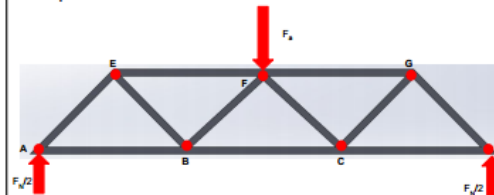
Step 1: Label where force is being applied



Step 2: Label the reactionary forces are



Step 3: Label Each Joint



#### Step 4: Set up Separate Free Body Diagrams for Each Joint

Joint A



#### Step 5: Sum the forces

$$F_A = 100 \text{ lbs} \quad F_N/2 = 50 \text{ lbs}$$

$$\Sigma F_y = F_N/2 + F_{AE} \sin(\theta) = 0$$

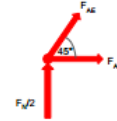
$$F_{AE} \sin(45) = -50$$

$$F_{AE} = -50/\sin(\theta) = -70.771 \text{ lbs}$$

$$\Sigma F_x = F_{AB} + F_{AE} \cos(\theta) = 0$$

$$F_{AB} = -F_{AE} \cos(45) = 50.043 \text{ lbs}$$

\*\* A negative sign indicates that the force is a compressive force\*\*



#### Joint E



#### Joint E

$$\Sigma F_y = -F_{AE} \sin(\theta) - F_{EC} \sin(\theta) = 0$$

$$F_{EC} = -F_{AE}$$

$$F_{EC} = 70.771 \text{ lbs}$$

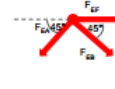
$$\Sigma F_x = -F_{AE} \cos(\theta) + F_{EC} \cos(\theta) + F_{AB} = 0$$

$$F_{EC} = F_{AE} \cos(45) - F_{AB} \cos(45)$$

$$F_{EC} = -100.085 \text{ lbs}$$

Given:

$$F_{AB} = -70.771 \text{ lbs}$$



#### Joint B



#### Joint B

$$\Sigma F_y = F_{AB} \sin(\theta) + F_{BE} \sin(\theta) = 0$$

$$F_{BE} = -F_{AB}$$

$$F_{BE} = -70.771 \text{ lbs}$$

$$\Sigma F_x = -F_{AB} \cos(\theta) + F_{BE} \cos(\theta) + F_{BC} = 0$$

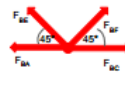
$$F_{BC} = F_{AB} \cos(45) - F_{BE} \cos(45)$$

$$F_{BC} = 150.128 \text{ lbs}$$

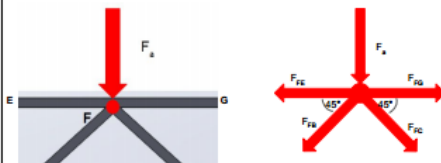
Given:

$$F_{AB} = 50.043 \text{ lbs}$$

$$F_{BE} = 70.771 \text{ lbs}$$



#### Joint F



#### Joint F

$$\Sigma F_y = -F_{BF} \sin(\theta) - F_{FC} \sin(\theta) - F_A = 0$$

$$F_{FC} = -F_{BF}$$

$$F_{FC} = -70.771 \text{ lbs}$$

$$\Sigma F_x = -F_{FC} \cos(\theta) + F_{FB} \cos(\theta) + F_{EG} = 0$$

$$F_{FC} = F_{FB} \cos(45) - F_{EG} \cos(45)$$

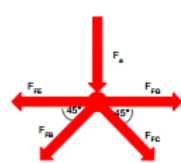
$$F_{FC} = -100.085 \text{ lbs}$$

Given:

$$F_{BE} = -70.771 \text{ lbs}$$

$$F_A = -100 \text{ lbs}$$

$$F_{EG} = -100.085 \text{ lbs}$$




$$\Sigma F_y = F_{CS} \sin(\Theta) + F_{CS} \sin(\Theta) = 0$$

$$F_{\text{ca}} = -F_{\text{ac}}$$

$$F_{09} = 70.771 \text{ lbs}$$

$$\Sigma F_x = -F_{BC} - F_{CS} \cos(\theta) + F_{CS} \cos(\theta) + F_{CD} = 0$$

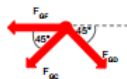
$$F_{\text{co}} = F_{\text{ac}} + F_{\text{of}} \cdot \cos(\Theta) - F_{\text{co}} \cdot \cos(\Theta)$$

$$F_{cd} = 50.043 \text{ lbs}$$

**Given:**

$$F_{MC} = 150.128 \text{ lbs}$$

$$F_{FC} = -70.771 \text{ lbs}$$


$$\Sigma F_y = -F_{co} \cdot \sin(\Theta) - F_{cc} \cdot \sin(\Theta) = 0$$

$$F_{gp} = -F_{pg}$$

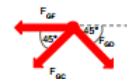
$F_{\text{CD}} = -70.71$

$$\Sigma F_x = -F_{\text{spring}} - F_{\text{spring}} \cdot \cos(\Theta) + F_{\text{spring}} \cdot \cos(\Theta) =$$

0

**Given:**

$$F_{CG} = 70.771 \text{ lbs}$$



The diagram shows a truss structure with nodes A, B, C, D, E, F, G, and H. The forces and reactions are as follows:

- Reaction at A:  $F_{A2} = 70.771$  lbs (upward)
- Reaction at D:  $F_{D2} = 70.771$  lbs (upward)
- Applied force at F:  $F_F = 100.085$  lbs (downward)
- Internal forces in the top chord:
  - $F_{DE} = -70.771$  lbs
  - $F_{EF} = -100.085$  lbs
  - $F_{FG} = -70.771$  lbs
  - $F_{GH} = -70.771$  lbs
- Internal forces in the bottom chord:
  - $F_{AB} = 50.043$  lbs
  - $F_{BC} = 150.128$  lbs
  - $F_{CD} = 50.043$  lbs
- Internal forces in the diagonal members:
  - $F_{BE} = 70.771$  lbs
  - $F_{CF} = 70.771$  lbs

Where do you think the bridge is going to fail?

- A member of a truss that carries no force.
- Why are they used then?
- Can act as a bracing to prevent a force-carrying member from buckling
- These members can carry loads if there are variations in where the force is applied

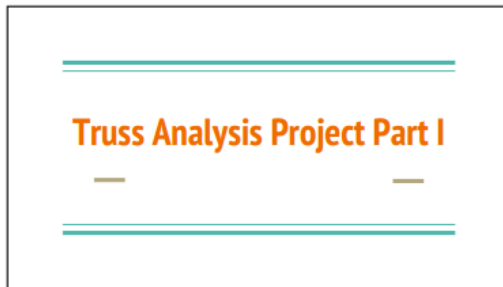
### Which bridge is better?

In this case because the force is being applied in the center the vertical members have no effect!



There can't be a counteracting force at the other end of the vertical members because force needs to be equal on both sides!

### A.3.1 Truss Project Part 1



#### Overview

##### Day 1:

Learning more about truss analysis.

Analyze trusses given in handout.

##### Day 2:

Break Trusses you analyzed in handout.

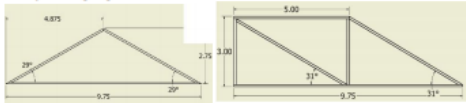
Get into teams to design your own truss

##### Day 3:

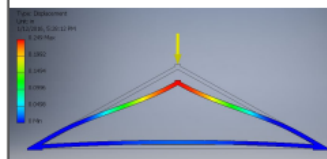
Break the trusses you designed and then analyze them.

#### Goals for today

Analyze bridges given in handout.



#### Force Applied Truss 1



Maximum Displacement: 0.25 in

Force Applied: 113lbf - 503 N

Mass: .012 lbs - .005 kg

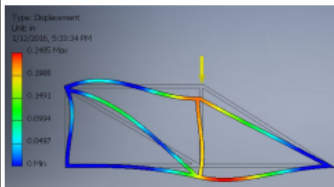
To get Newtons

$N = \text{mass(in kg)} * \text{gravity}$

Gravity = 9.81 m/s<sup>2</sup>

beginfigure[H]

#### Force Applied Truss 2



Maximum Displacement: 0.25 in

Force Applied: 31lbf - 138N

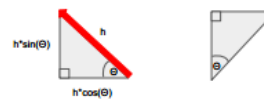
Mass: .022 lbs - .01 kg

To get Newtons

$N = \text{mass(in kg)} * \text{gravity}$

Gravity = 9.81 m/s<sup>2</sup>

#### Summing forces when given force at angle



\*\* Note that  $h \sin(\theta)$  is not always the y component and  $h \cos(\theta)$  is not always the x component!

Use  $h \sin(\theta)$  to find the component that is opposite from the angle given.

Use  $h \cos(\theta)$  to find the component that is adjacent to the angle given.

### A.3.2 Truss Design

#### Truss Design

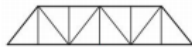
#### Warren Truss

- A truss that contains a series of isosceles triangles or equilateral triangles. To increase the span length of the truss bridge, verticals are added.



#### Warren Truss Advantages

- Is able to spread load evenly when load is a **distributed load**
- Simple
- Cost-effective



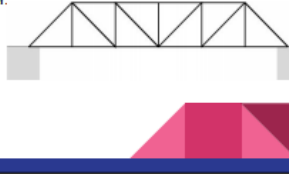
#### Warren Truss - Disadvantages

- Is not able to spread load on members evenly when a **point load** is applied



## Pratt Truss

- A Pratt truss includes vertical members and diagonals that slope down towards the center.

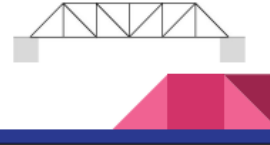


## Pratt Truss Advantages

- Longer diagonal members are in tension and the shorter vertical members are in compression.
- The amount of material for diagonal members can be reduced making it more efficient and cost effective.

Note:

- Members in tension fail because the member is stressed to its maximum capacity
- Members in compression fail because of buckling
- Buckling- bend and give way under pressure or strain



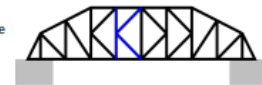
## Pratt Truss - Disadvantages

- More difficult to construct using traditional methods of construction
- If the load is not vertical, it is not as advantageous



## K Truss

- A truss in the form of a K due to the orientation of the vertical member and that it has two members that are neither parallel nor a right angle to the vertical member in each panel.



## K Truss Advantages

- Reduced compression in vertical members.



## K Truss - Disadvantages

- More complicated
- Not as easy to predict behavior



## Specifications

7" in length

1.25" in width

.25" thick



Members can be any thickness as long as it fits in the 7" by 1.25" x .25" box.

**Bridges will be judged on EFFICIENCY!**



### A.3.3 Free Body Diagrams

#### Free Body Diagrams

What are they? How do I use them?

#### What are they?

A Free Body Diagram is a visual representation of instantaneous forces interacting with objects.

#### What is a Force?

A Force is a straight push or pull vector acting on an object.

A vector has both a magnitude and an angle.

These forces can be broken down into x and y components with simple geometry



#### Center of Mass

Each body has a center of mass.

The location where we consider all of the mass to be concentrated.



beginfigure[H]

### Concept Examples

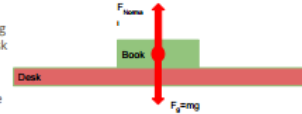
Suppose a book is on your desk;  
The book has weight and is pushing down on the desk, does this mean that the desk is pushing up on the book?



### Concept Examples

Suppose a book is on your desk;  
The book has weight and is pushing down on the desk, does this mean that the desk is pushing up on the book?

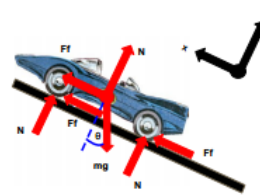
Yes! The book is not falling through the desk, the desk is rigid and is supporting the weight of the book, therefore it is pushing the book's weight up.



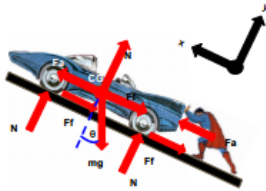
### 8 Steps Solving Problems with Free Body Diagrams

1. Indicate coordinate axis frame (x/y)- up to you
2. Identify forces and indicate them through drawing arrows with proper magnitude and direction
3. Label Center of Gravity
4. Redraw forces coming from center of gravity
5. Break the forces down into components
6. Redraw the free body diagram
7. Sum the forces in x
8. Sum the forces in y

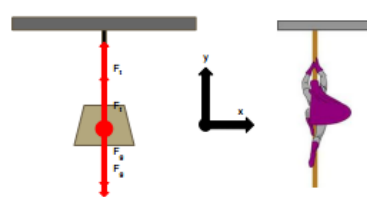
### Example 1: Incline Plane



### Example 1: Incline Plane



### Example 2: Cable Tension



### Summing forces when given force at angle

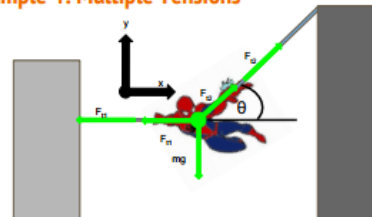


\*\*\* Note that  $h \sin(\theta)$  is not always the y component and  $h \cos(\theta)$  is not always the x component!

Use  $h \sin(\theta)$  to find the component that is opposite from the angle given.

Use  $h \cos(\theta)$  to find the component that is adjacent to the angle given.

### Example 4: Multiple Tensions





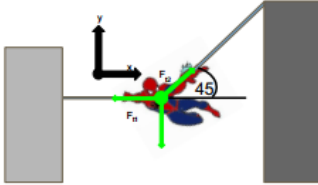
### Example 3: Multiple Tensions

Given:

- Spiderman Weight = 70kg
- Acceleration Due to Gravity =  $9.8 \text{ m/s}^2$
- Angle of  $F_{12}$  =  $45^\circ$  from horizontal

Find:

- $F_{12}$  = ?
- $F_{13}$  = ?



### Interactive Activity / You Try It

- Use plastic arrows with magnets to point and show forces on white board

## A.3.4 Introduction to Materials

# Materials

### What are materials?

Materials are the substances of which all things are made and are composed of different elements.

Material Science drives the designs of several products

They all have different properties that make them suitable for different applications including strength, chemical properties thermal properties ect.

Example:

Material chosen for your shoe should be sturdy, yet flexible



### Classification of Materials

There are 4 main categories of materials.

- Ceramics
- Metals
- Polymers
- Composites

### Ceramics

Definition: inorganic, non-metallic materials made from compounds of a metal and a non-metal

Properties:

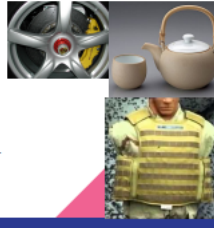
- Hard
- Brittle
- High Strength
- Good Thermal Insulator
- Good Electrical Insulator
- Can be very high cost

\*\* Thermal Insulator- resists the flow of heat

\*\* Electrical Insulator - resists the flow of electricity

### Applications - Ceramics

- Used in brake disks for cars- low wear, very hard material SiC
- Used in bullet-proof vests - this application takes advantage of ceramics being brittle. Ceramics are very hard, strong, brittle materials. When a bullet is shot at a hard ceramic material such as Silicon Carbide, the energy dissipates when the material shatters.
- Also used as thermal insulators for common household items such as dishes



### Metals

#### Properties:

- Moderate Hardness
- Moderate Strength
- Ductile - capable of large amounts of deformation without fracture
- Good Electrical Conductors
- Good Thermal Conductors
- Can be very high cost depending on which metal is used

### Applications - Metals

Metals are used in several different applications because it is strong, but ductile making it suitable for airplane and other vehicles.

Its strength and ductile properties are beneficial for tools such as hammers as well as fasteners like nuts and bolts.

The electrical conductivity of metals is also taken advantage of in several electronic devices such as computers and smart phone.



### Polymers

- Low Hardness
- Low Density
- Ductile
- Pliable
- Chemically inert - does not react to chemicals
- Low melting temperature
- Low electrical conductivity
- Low Cost



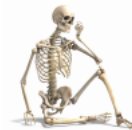
### Applications - Polymers

- Different containers - food storage, drink storage
- Parts for all sorts of equipment - but cannot be used for high temperature applications or high stress
- used in many everyday products because it is easy to form and mold due to its low melting temperature.



### Composites

- A composite is a material composed of two or more individual materials that come from the categories of metal, ceramic, and polymers.
- They are used to achieve combined properties of different types of materials that may be suitable for an application where not just one type of material would work the best.
- Composites are not just man-made. Many composites are found in nature such as bone.
- Relatively low cost



### Applications - Composites

- Fiber-glass - small glass fibers are set in a plastic.
- The combination of plastic and glass fibers makes a stiff, strong, flexible, lightweight material.
- Fiber-glass is used for many applications, in particular, parts for cars.



### Exercise - Check your understanding

What types of material would be best used for a car engine and why?

Which type of material would be best used for fishing lines and why?

Which material category does wood belong too?

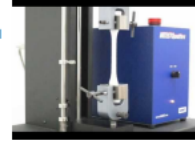
Choose an item that you use everyday and list which materials it is made up of and why you think those materials were chosen.

### A.3.5 Materials Testing

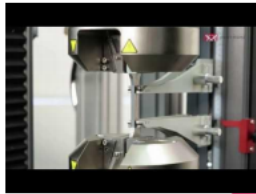
## Materials Testing

Tensile Testing - a test where a material specimen is pulled on both sides lengthwise until the point of fracture.

Typically, these specimens are in the shape of a "dog bone" so that the deformation of the specimen is confined towards the narrow center region.



### Tensile Testing Video



### Elastic and Plastic Deformation

Deformation - the action or process of changing in shape or distorting, especially through the application of a load.

Elastic Deformation - deformation that is nonpermanent; totally recovered upon release of applied stress.

Plastic Deformation - deformation that is permanent; non-recoverable upon release of applied stress.

### Example - Elastic Deformation

When you stretch a rubber band at its normal load, it is easily able to go back to its original shape.

Elastic deformation does not mean that it only applies to rubber or stretchy materials, all materials can undergo elastic deformation.

The stress-strain curve in the next few slides will help explain why.



### Example Plastic Deformation

When you form clay, it does not spring back to its original shape when pressure is applied. It undergoes plastic deformation and retains its new shape.

Plastic deformation can happen in all materials, it just means that enough stress was applied to cause a permanent change to the physical material specimen. In terms of tensile tests, it occurs for many materials in the form of elongation.



### Stress-Strain Curve

- What is it? - This is the curve relating the elongation of materials when tensile stresses are applied to a specimen
- What is stress? - The instantaneous load applied to a specimen divided by its cross-sectional area.
- What is strain? - The change in length of a specimen in the direction of applied stress divided by its original length



### Stress-Strain Curve Part 2

Many different materials properties can be obtained through studying a stress-strain curve including:

Young's Modulus - The ratio of stress to strain when deformation is totally elastic.

Ultimate Tensile Strength -

Yield Strength -

Fracture Toughness-



### Stress Strain curve Demo Example



### Hands on Demo with 3D Printed Objects

Show different types of deformation

Different Materials properties and how that relates back to the stress/strain curve



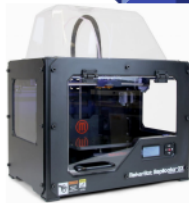
## Common Reasons for why materials fail

- High continuous static (not moving) stress
- High temperature - can make deformation easier and the material can fail as the temperature gets closer and closer to the material's melting point
- Low temperature - in several materials, this can make them brittle and more likely to fail. (in metals, low temperatures virtually eliminate their ductile properties making them very brittle.
- Cyclic stress ( constant wear from stress being applied and removed in different parts of a product) example bicycle.



### A.3.6 How to 3D Print

#### How to 3D Print




#### Outline

- Saving your part as an STL
- Loading part into MakerBot Desktop
- Tools for Orienting Part
- Optimizing Orientation of Parts
  - Things to watch out for
  - Incorrect way to orient parts
  - Correct way to orient parts
- Setting printer as proper model
- Settings
- Saving as .thing file

#### Saving Your Part as an STL

#### Saving Part as STL

In Inventor Go to:

 at top left corner of screen -  
> Export -> CAD Format -> Save  
as Type and choose STL  
(stereolithography)

\*\*\*Make sure you click to options  
button to make sure the units are  
in mm\*\*\*

## Loading Part Into MakerBot Desktop

Open up MakerBot Desktop

Go to:

File -> Open -> choose your file for initial file opening

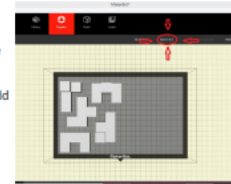
To add other parts to the platform go to "Add file" in the top center of the screen.

## Adding Additional Parts to Build Plate

Go to:

File -> Open -> choose your file for initial file opening

To add other parts to the platform go to "Add file" in the top center of the screen.



## Tools for Orienting Parts

## Overview

In MakerBot Desktop there is a toolbar on the left side of the screen.

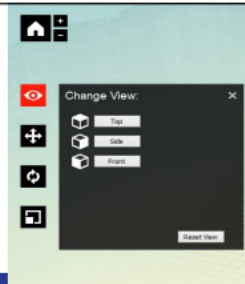
The tools on this toolbar include:

- View
- Position
- Rotation
- Dimensions

## View

When this icon is selected a menu pops up allowing you to go to Top, Side, or Front View.

If you want to look at a specific feature that is hard to look at with these views you can also click and drag the screen to change the view



## Position

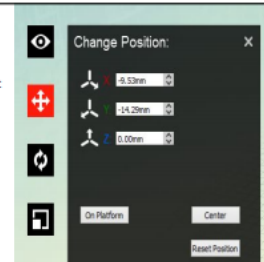
This tool allows you to move the part:

X - (From left to right)

From front to back(Y)

Up and down(Z)

This can be done by typing in values in the fields or by dragging the part.



## Rotation

This tool allows you to rotate your part around the X, Y, and Z Axes.

This can be done by:

Pressing the +/- 90 buttons next to the appropriate axis

Dragging the part

Typing in Values

**NOTE: Once you are finished rotating click "Lay Flat" to make sure that your part is not floating**



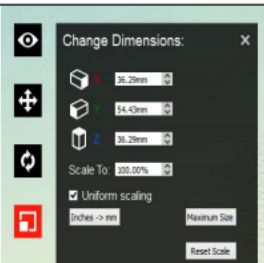
## Dimensions

This tool allows you to scale your parts.

This can be done by typing in your scale factor in percentages.

For example:

If you want your cube to be half the size it currently is type 50% in the "Scale To" field



## Orientation of Parts

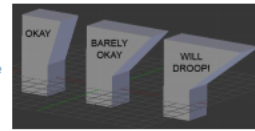
### Over hang

Definition: Parts of your print that are unsupported by its own structure.

Why is this bad?

This type of feature requires support material making the print take longer in terms of time on the printer and print finishing.

Avoid overhang when possible either through the orientation of your part or through design for 3d printability.



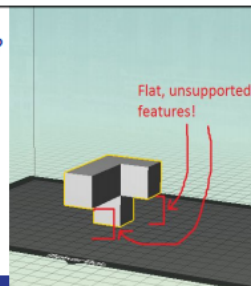
### Things to Watch Out For

- Is your part in the best possible position?
  - Does my part need support material?
  - Is there a way to orient it so that I don't need it?
- Is my part laid flat on the bed

### Examples of Incorrect Ways to Orient Parts

### What is wrong with this?

- Will have over hang!
- Will require support material!!
- Can be fixed!



### What's wrong with this?

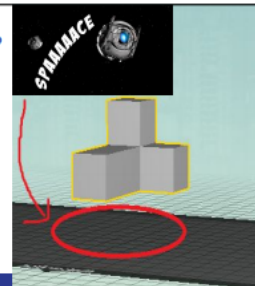
There is space between the build plate and the part!

This can be fixed by going to:

Position and clicking "On Platform"

or

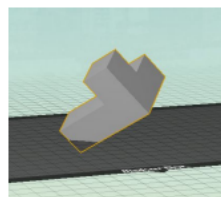
Rotation and clicking "Lay Flat"



### Whoa

This can still be fixed by going to:

Rotation and clicking "Lay Flat"



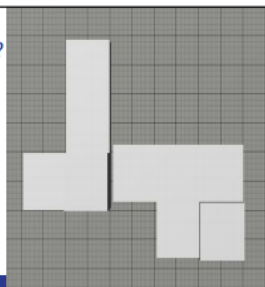
### What is wrong with this?

There is not enough space between the parts.

The spacing between parts must be at least 5mm ~.20 in

Each larger grid square is 10mm

Each smaller grid square is 2mm



## How to Correctly Orient a Part

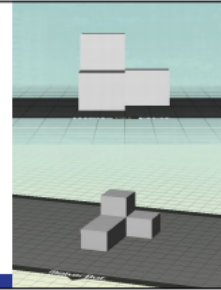
## Good Practice

This part is oriented such that:

There is no overhang

It is laying flat on the bed by pressing the

"Lay Flat" button in the Rotation menu



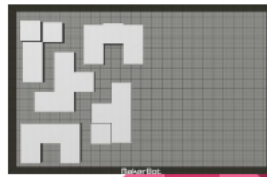
## Multiple Parts

Each part is spaced so that they are far enough away from each other

They are oriented to get rid of overhang

Not spread out too far.

Even if you are just printing your parts it is better to keep the parts closer together to reduce the time it takes to print. The print head does travel moves and that takes time.



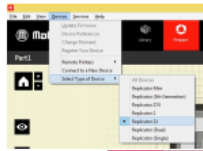
## Setting Printer As Proper Model

## Setting Printer As Proper Model

Go to:

Devices -> Select Type of Device ->

Select Replicator 2x



## Print Settings

## Important Settings

Layer Height - How thick the print layers are. Larger layer height = Lower resolution

Number of Shells - number of outside walls on the print. (Increase for greater rigidity)

Support - Adds supports to the print where needed

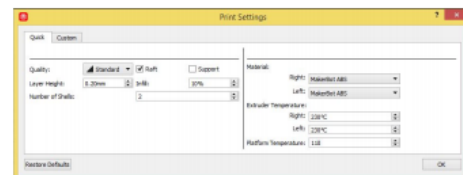
Infill - The density of the part. (Increase percentage for greater rigidity)

Raft - Bottom skirt of print that prints out before the rest of the part. Is larger and outlines the part. Prevents warping of the part and helps it stick to the bed

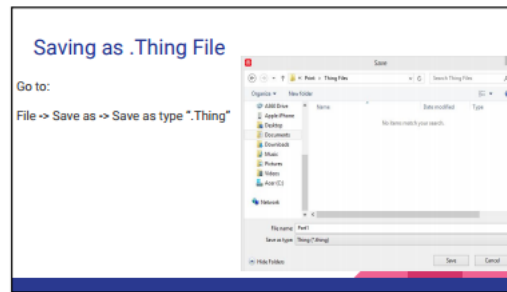
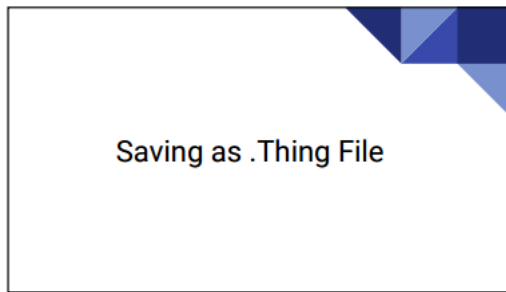
Material - Assigns certain settings for different materials

Extruder and Platform Temperature - adjust for material choice

## Standard Settings to Input







## A.4 Survey

### The Impact of 3D Printing for Education

#### Welcome to My Survey

You are invited to take part in a research survey about the impact of incorporating 3D Printing into your engineering class's lesson plans. Your participation will require approximately 15 minutes and is completed online at your computer. There will be no disclosure of identifying information or discomforts associated with this survey. This survey will benefit the curriculum being developed through providing feedback for future improvements. These improvements can benefit students being taught the material in future engineering classes. Taking part in this study is completely voluntary. If you choose to be in the study you can withdraw at any time. Your responses will be kept strictly confidential, and digital data will be stored in secure computer files. Any report of this research that is made available to the public will not include your name or any other individual information by which you could be identified. Thank you for participating in our survey. Your feedback is important.

Next

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 SurveyMonkey®  
[See how easy it is to create a survey](#)

1. Rate the following statements on scale of Strongly Agree to Strongly Disagree

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I learned new information about 3D printing.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I was inspired to think creatively about 3D printing.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The incorporation of 3D printing was helpful in understanding engineering concepts.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The incorporation of 3D printing stimulated your interest in engineering.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The lesson plans were helpful in terms of understanding the material.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The hands on exercises aided in the understanding of the subject material.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would like to see 3D printing incorporated into my other engineering classes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would like to see 3D printing incorporated into my other non-engineering classes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The overall experience with the visitors was positive.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2. Are there any additional engineering topics that you would have liked to learn?

3. Can you suggest any other projects where 3D printing would be beneficial? (This can include projects that you have already done.)

4. Suggest any improvement in the lesson plans:  
ex: I wish they could have given more instruction on CAD.

Prev

Next

## The Impact of 3D Printing for Education

THANK YOU!

Thank you for participating in this survey!

Prev

Done

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See how easy it is to [create a survey](#).



## A.5 Raw Survey Results

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total	Weighted Average
I learned new information about 3D printing.	30.00% 3	60.00% 6	10.00% 1	0.00% 0	0.00% 0	10	1.80
I was inspired to think creatively about 3D printing.	60.00% 6	10.00% 1	30.00% 3	0.00% 0	0.00% 0	10	1.70
The incorporation of 3D printing was helpful in understanding engineering concepts.	70.00% 7	30.00% 3	0.00% 0	0.00% 0	0.00% 0	10	1.30
The incorporation of 3D printing stimulated your interest in engineering.	60.00% 6	40.00% 4	0.00% 0	0.00% 0	0.00% 0	10	1.40
The lesson plans were helpful in terms of understanding the material.	60.00% 6	40.00% 4	0.00% 0	0.00% 0	0.00% 0	10	1.40
The hands on exercises aided in the understanding of the subject material.	60.00% 6	40.00% 4	0.00% 0	0.00% 0	0.00% 0	10	1.40
I would like to see 3D printing incorporated into my other engineering classes.	60.00% 6	20.00% 2	20.00% 2	0.00% 0	0.00% 0	10	1.60
I would like to see 3D printing incorporated into my other non-engineering classes.	30.00% 3	20.00% 2	40.00% 4	10.00% 1	0.00% 0	10	2.30
The material was presented in a fashion that was easy to follow.	40.00% 4	40.00% 4	10.00% 1	10.00% 1	0.00% 0	10	1.90
The overall experience with the visitors was positive.	80.00% 8	20.00% 2	0.00% 0	0.00% 0	0.00% 0	10	1.20